Permeable Reactive Barriers

September 12, 2002
NJDEP Public Hearing Room
Sponsors: NJDEP & ITRC

1:00 - 1:15 **Welcome & ITRC Update**

Brian Sogorka, NJDEP Remediation Technology Manager

1:15 - 3:45 **Technical Program**

Matthew Turner, NJDEP, Moderator

1:25 - 2:10 **Overview of Granular Iron PRBs for VOC Treatment**

Michael L. Duchene, M.A.Sc., P.Eng., EnviroMetal Technologies, Inc.

2:10 - 2:55 **Injection of Zero Valence Iron Powder for Insitu Chemical Reaction**

John J. Liskowitz, ARS Technologies, Inc.

2:55 - 3:40 **Permeable Reactive Barriers Design and Installation**

Paul Boyajian and Steve Brauner, Parsons

3:40 - 3:45 Wrap-up

Permeable Reactive Barriers

INTERSTATE TECHNOLOGY REGULATORY COUNCIL ITRC

Introduction:

Brian Sogorka,
NJDEP Remediation Technology Manager

Regulatory Acceptance for New Solutions

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Purpose of ITRC

ITRC is a state-led, national coalition of regulators and others working to

- improve state permitting processes and
- speed implementation of new environmental technologies.

Goals

- Achieve better environmental protection through innovative technologies
- Reduce the technical/regulatory barriers to the use of new environmental technologies
- Build confidence about using new technologies

Other Participants

- Industry representatives
- Academia
- Public stakeholders
- Federal agencies
  - U.S. Department of Energy
  - U.S. Environmental Protection Agency
  - U.S. Department of Defense
- Host organization
  - Environmental Council of the States (ECOS)
- State organizations
  - Western Governors' Association
  - Southern States Energy Board

Products & Services

- Regulatory and Technical Guidelines
- Technology Overviews
- Case Studies
- Peer Exchange
- Technology Advocates
- Classroom Training Courses
- Internet-Based Training Sessions

Active Technical Teams

- Alternative Landfill Technologies
- Brownfields
- Constructed Wetlands
- Contaminated Sediments
- Dense Nonaqueous Phase Liquids
- Diffusion Samplers
- DOE Gate 6 Technologies
- In Situ Bioremediation
- MTBE-Contaminated Groundwater
- Permeable Reactive Barriers
- Radionuclides
- Remedial Process Optimization
- Sampling, Characterization, and Monitoring
- Small Arms Firing Range
- Unexploded Ordnance

Nationwide Success

Contacts

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Technical Program

Matthew Turner
NJDEP, Moderator

ITRC Permeable Reactive Barriers Team
Matthew Turner,
Site Remediation Program, NJDEP

Permeable Reactive Barriers for Groundwater Remediation
Paul Boyajian and Steve Brauner,
Parsons

Overview of Granular Iron PRBs for VOC Treatment
Michael L. Duchene, M.A.Sc., P.Eng.,
EnviroMetal Technologies, Inc.

Injection of Zero Valence Iron Powder for *In situ* Chemical Reaction
John J. Liskowitz,
ARS Technologies, Inc.

ITRC
Permeable Reactive Barriers Team

Documents

1) Regulatory Guidance for Permeable Reactive Barriers Designed to Remediate Chlorinated Solvents
December 1999 (2nd Edition)

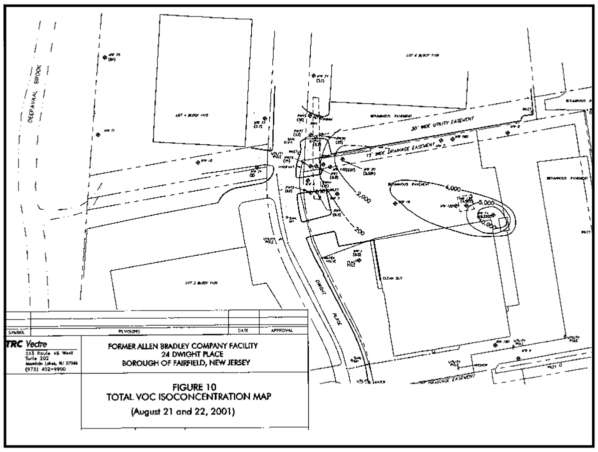
2) Regulatory Guidance for Permeable Reactive Barriers Designed to Remediate Inorganic and Radionuclide Contamination
September 1999

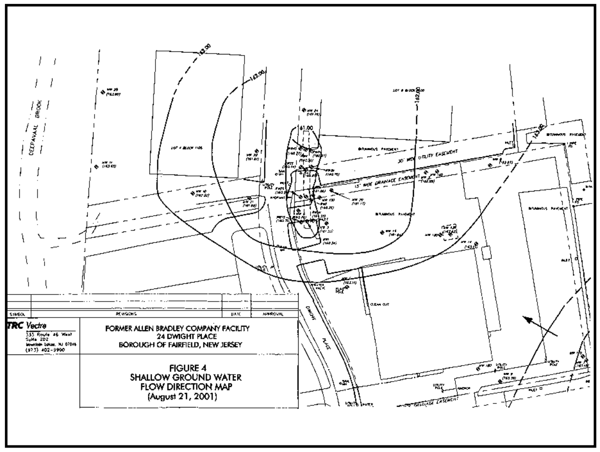
ITRC
Permeable Reactive Barriers Team

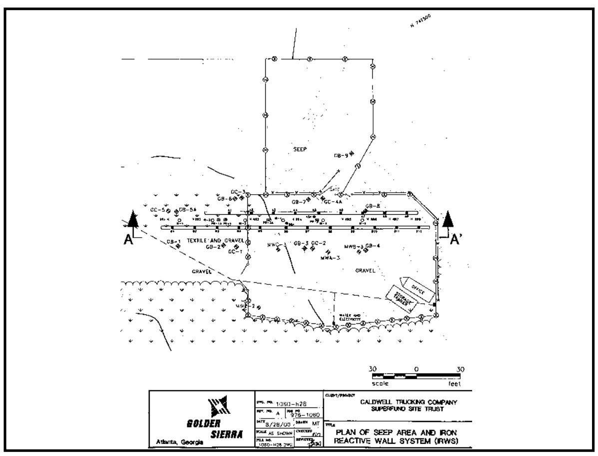
Documents

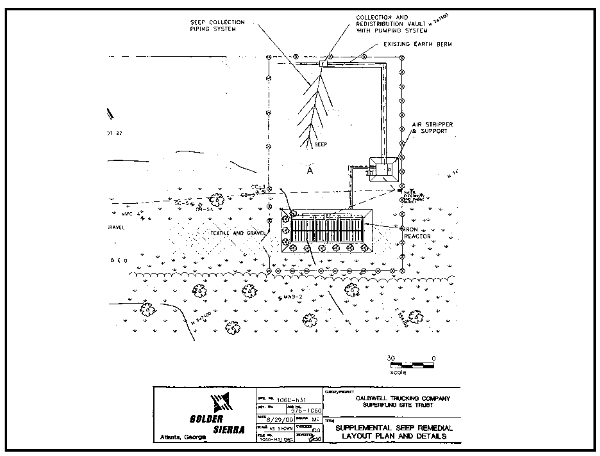
3) Design Guidance for Application of Permeable Barriers for Groundwater Remediation
March 2000

4) Draft Report - Permeable Reactive Barrier Performance and Guidance
April 25, 2002









Permeable Reactive Barriers for Groundwater Remediation

Presented by

Steve Brauner, Ph.D.
Paul Boyajian, P.E.
PARSONS

Presented to

NJDEP SRP
September 12, 2002

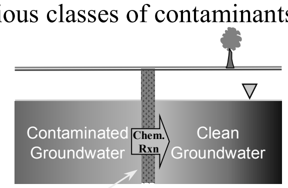
Presentation Outline

- Theory
- Pre-design investigation
- Remedial design
- Installation techniques
- Case study

Parsons

Theory

- 'Passive' approach
- Various classes of contaminants treated



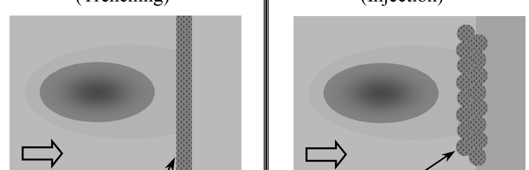
Reactive Media
(e.g. PRBs and injections)

Parsons

PRB Configurations – Plan (1)

Continuous Barrier (Trenching)

Continuous Barrier (Injection)

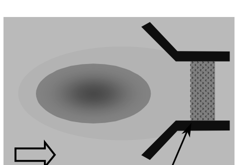


Reactive Media

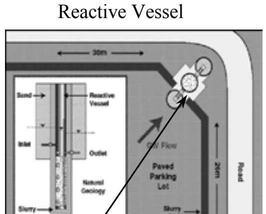
Parsons

PRB Configurations – Plan (2)

Funnel and Gate



Reactive Vessel



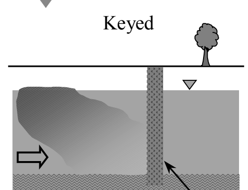
Schematic courtesy of ETI

Reactive Media

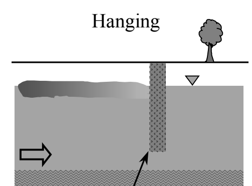
Parsons

PRB Configurations – Profile

Keyed



Hanging



'Key' material
(e.g. clay, till, bedrock)

Reactive Media

Parsons

Reactive Media

- Purpose: Alter or enhance local subsurface environment to favor contaminant removal
- Contaminant removal mechanisms
  - — Abiotic degradation
  - — Enhanced biodegradation
  - — Precipitation
  - — Sorption
- Some materials/processes are patented

Reactive Media

	Reactive Iron	Organic Carbon	GAC	O_2 Delivery	Zeolites
CAHs	➸	➸	➸	➸	
Metals Cr(VI), As, Cu, Ni	➸	➸			➸
Acid Mine Drainage		➸			
PHCs			➸	➸	
Nitrate		➸			

Pre-design Investigation

- Purpose:
  - — Identify potential backfill materials;
  - — Perform treatability testing, as needed;
  - — Obtain subsurface information for design and construction purposes;
  - — Estimate local groundwater velocity; and
  - — Identify subsurface anomalies.

Pre-design Field Investigation

- Geologic
  - — Hydraulic conductivity
  - — Soil properties
  - — Key material
  - — Excavation effort
  - — Boring spacing
  - — Blow counts
- Geochemical
  - — Contaminants of concern
  - — Redox condition
  - — "Inhibitor" compounds

Pre-design Lab Testing

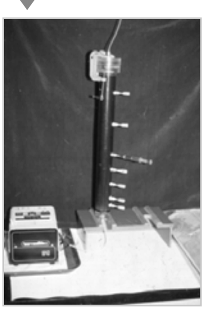


Photo courtesy of ETI

- Treatability Testing
  - — Bench-scale
  - — Rate of contaminant removal
  - — Compare various media types/combinations
  - — Particularly important when "inhibitor compounds" are present
- Biopolymer slurry compatibility
  - — Estimate 'in-trench' stability time via viscosity measurements
  - — Evaluate various biopolymers
  - — Necessity of additives

Design Considerations

Critical Questions	*Controlling Factors*	*Design Criteria*
1. Treatment capacity	Contaminant mass	Reactive media mass
2. Residence time	Rate of reaction; Local groundwater velocity	PRB thickness
3. PRB alignment & installation technique	Buildings/Utilities; Soil conditions; Contaminant depth	Selection of reactive media delivery technique
4. PRB longevity	Mineral precipitation; Loss of reactivity	Sand addition; Bench-scale testing

Primary Design Documents

- Alignment drawing(s)
- Cross-section drawing(s)
- Monitoring locations
- Technical specifications

Installation Techniques

- Trenching
  - Traditional (open) trenching to water table depth
  - Continuous trenching to 25’ feet below land surface
    - Custom-built machinery that excavates and places backfill in single ‘pass’
  - Biopolymer slurry trenching to 100’ feet below land surface or more
    - Provides temporary support during excavation, allowing trench to be backfilled with a material of choice
- Injections
  - Pnuematic
  - Liquid

Continuous Trenching

Slurry Trenching

Excavation in the “dry” can lead to failure, so…

Slurry Trenching

… use a slurry to support the walls of the trench.

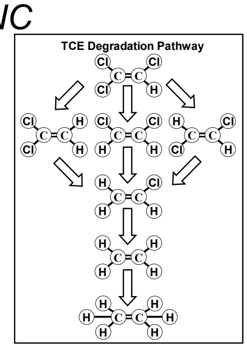
Case Study – USCG Station Elizabeth City, NC

- Influent contaminants
  - [TCE] ~ 4 ppm
  - [Cr(VI)] ~ 10 ppm
- Zero valent iron backfill
  - TCE removal via abiotic reductive dechlorination (Irreversible)
  - Cr(VI) removal via chemical precipitation (Potentially reversible)

Cr(VI) Removal Pathway

Cr(VI) $\rightarrow$ Cr (III)

More Soluable *Less Soluable*

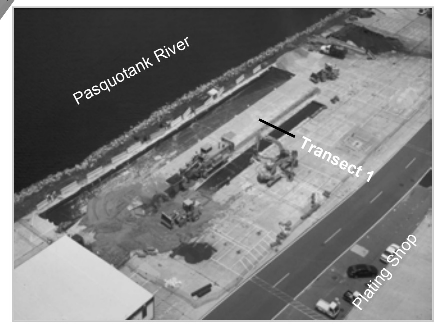


Elizabeth City - Specifications

- Installed in June 1996
- Continuous PRB
  - Hanging PRB
  - 150 ft length
  - 2 ft flow-through thickness
  - 100% Iron
  - 26 ft total depth
  - 18 ft saturated depth
- Groundwater velocity
  - 0.5 ft/day

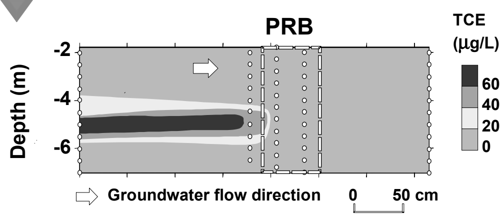
Photo courtesy of ETI

Elizabeth City - Alignment



Source: University of Waterloo
Slide courtesy of ETI

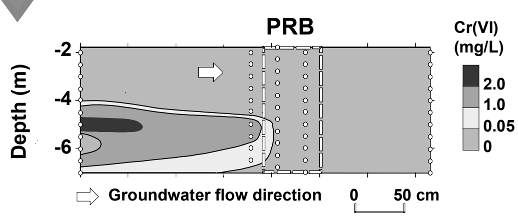
Elizabeth City – TCE Profile



TCE in Transect 1 (after 2.5 years)

Source: EPA/600/R-99/095b, Blowes et al. (1999)
Slide courtesy of ETI

Elizabeth City – Cr(VI) Profile



Cr(VI) in Transect 1 (after 2.5 years)

Source: EPA/600/R-99/095b, Blowes et al. (1999)
Slide courtesy of ETI

Summary

- PRBs may offer a cost-effective method for in situ groundwater treatment through reduced O&M costs;
- Various reactive media are available with selection based on contaminants of concern and existing/desired groundwater redox condition; and
- Installation technique for reactive media in situ placement depends on site's physical constraints, plume dimensions, and geology.

Thank you.

Questions?

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Overview of Granular Iron PRBs for VOC Treatment

Michael L. Duchene
Senior Engineer
EnviroMetal Technologies Inc.

enviro**metal** technologies inc.

Chlorinated Organic Degradation Using Granular Iron PRBs

- Developed and patented by the University of Waterloo
- Commercialized through EnviroMetal Technologies Inc.
- Over 75 field-scale installations
- First full-scale application completed February 1995
- Sites in North America, Europe, Australia and Japan

Advantages

Passive, Simple Process

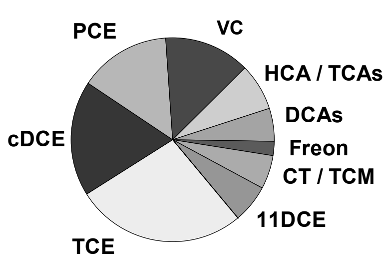
- degrades a wide range of chlorinated organics
- contaminants destroyed
- nontoxic end products
- no energy or equipment
- conserves water
- allows productive use of site

"The most intriguing idea that has emerged in the remediation field."
—Lynn Roberts, Ph.D.
The Johns Hopkins University

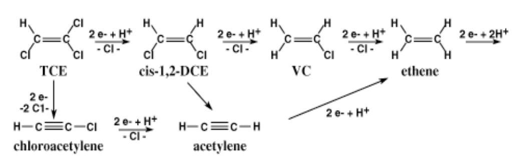
Granular Iron

Grain size: -8 to +50 mesh
Bulk density: 150 lb/ft^3
Surface area: ~ 1.0 m^2/g
Hydraulic conductivity:
5 x 10^{-2} cm/sec (142 ft/day)
Cost: ~ $350 ton + shipping

VOCs Treated in Iron PRBs

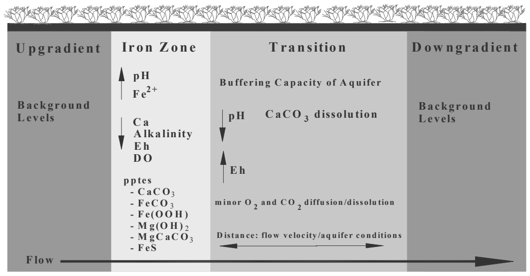


Degradation Process



- Reaction is abiotic reductive dehalogenation
- Reaction occurs on surface of iron
- Prominent pathway is the Beta-elimination pathway (through chloroacetylene and acetylene)

Inorganic Chemistry



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Precipitate Formation and Effect

- carbonate precipitates begin at upgradient interface
- long-term laboratory simulations indicate precipitate formation over several years cause some permeability loss and significant reactivity loss
- no evidence of hydraulic / reactivity losses in the field over 7 years of operating record

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PRB Implementation – ETI Involvement

1. Cost Estimate
2. Site Data Assessment
3. Bench-Scale Test / ETI Database
4. Design / Costing / Construction

   site license fee provides use of patented technology at a site
5. Long–Term Performance Monitoring

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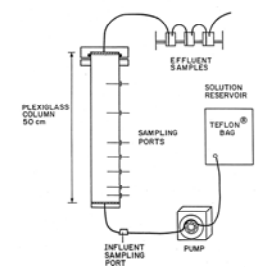
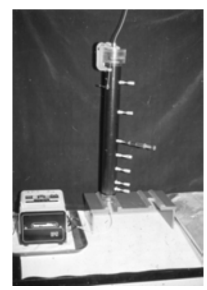
Column Treatability Study





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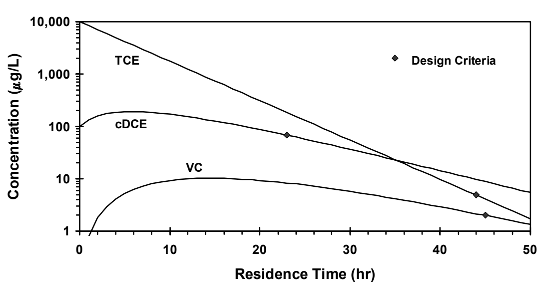
Residence Time Requirement



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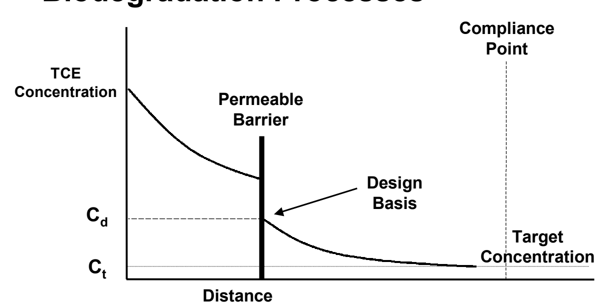
Combining PRBs with Natural Biodegradation Processes



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Treatment Zone Dimensions

Iron Thickness = Residence time (RT) required X Flow Velocity (FV) through treatment zone

Iron Volume = Thickness x Width x Sat. Depth

Safety factor / probabilistic design ?

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Design Considerations

- **groundwater velocity**
- **plume dimensions – width, depth, saturated depth**
- **residence time requirement - PRB flow through width**
- **geology**
- **installation method**

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Treatment Cost - 1999 Installations

	Construction	Iron	Total
Backhoe Construction, OH • 8 ppm TCE • 20 ft deep, 200 ft long	$36,000	$28,000	$64,000
BioPolymer Trench, NH • 10 ppm cDCE; 5 ppm TCE; 1 ppm VC • 33 ft deep, 150 ft long	$200,000	$130,000	$330,000
Trench Box, WY • 21 ppm TCE; <1000's ppb cDCE, VC • 23 ft deep, 565 ft long	$255,000	$745,000	$1,000,000

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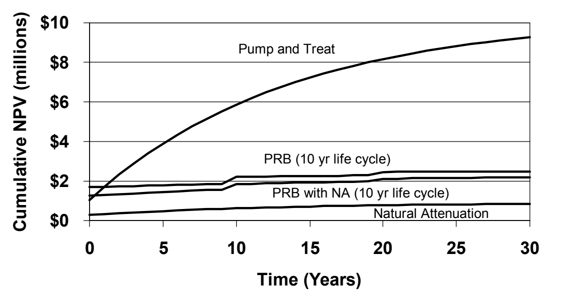
Cost Comparison

TCE Plume (10 mg/L), 400 ft wide, 80 ft deep



Source: DuPont 2000

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Full-Scale System Construction

35 Continuous Reactive Walls
- biopolymer (11)
- cofferdam (8)
- continuous trencher (6)
- hydrofracturing (3)
- supported excavation (3)
- open trench (2)
- trench box (1)
- jetting (1)

12 Funnel and Gate Systems
- slurry wall (6)
- sheet piling (4)
- HDPE (2)

3 In-situ Reactive Vessels

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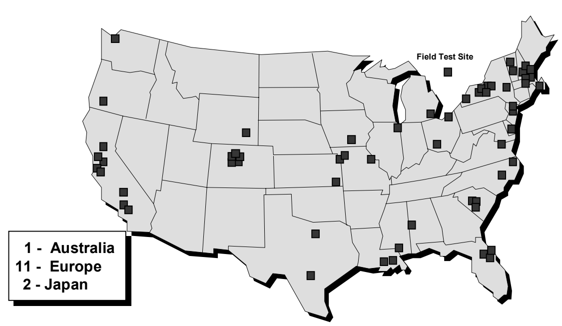
United States Field Installations



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Needham, MA

Continuous PRB
- Installed June/July 2001
- 510 ft total length
- 2 zones - 0.5 ft / 1.7 ft
- 31 ft average saturated depth
- 57 ft maximum depth

Groundwater Flow Velocity:
- 3.1 ft/day (design)

Influent Groundwater:
- 81 ppb TCE (design)

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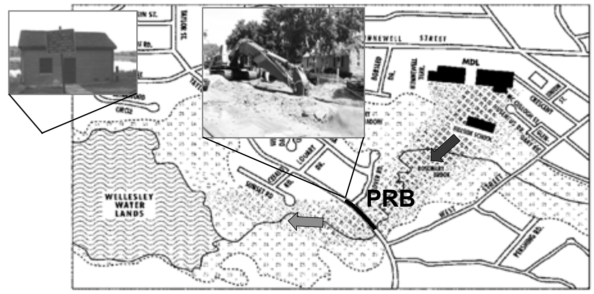
Needham, MA



Source: MADEP /Harding ESE

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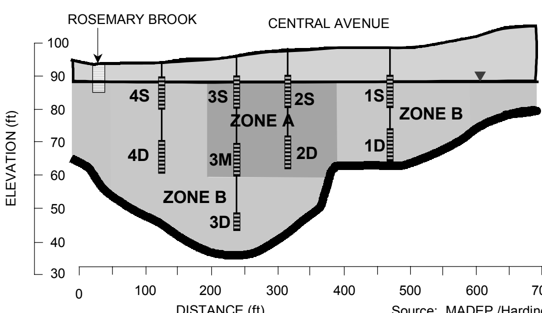
Needham - Cross-Section



Source: MADEP /Harding ESE

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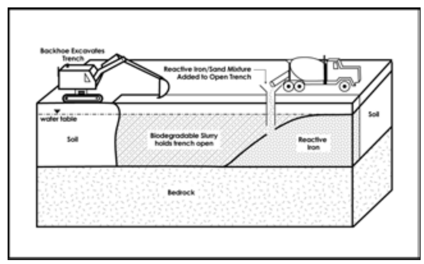
Biodegradable Slurry Trench Excavation



- **trench is excavated**
- **slurry consists of guar gum, bacteriostat, pH adjustment, enzyme**
- **Slurry level maintained above watertable**
- **Iron/sand placed in trench**
- **slurry breaks down allowing groundwater to move through PRB**

Schematic: GeoSyntec Consultants

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Warren AFB, WY

Continuous PRB
- Installed Oct 1999
- 568 ft total length
- 3 segments
- 4 ft / 1 ft / 1.5 ft of iron
- 15 ft saturated depth
- Hanging PRB

Groundwater Flow Velocity:
- 1.3 ft/day

Influent Groundwater:
- 25 ppm total VOCs

Source: AFCEE / URS Corporation, 2001

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Trench Box Construction

AFCEE, URS, Montgomery Watson, 2000

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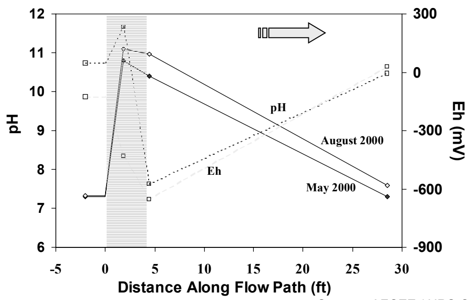
Warren AFB, WY



Source: AFCEE / URS Corporation, 2001

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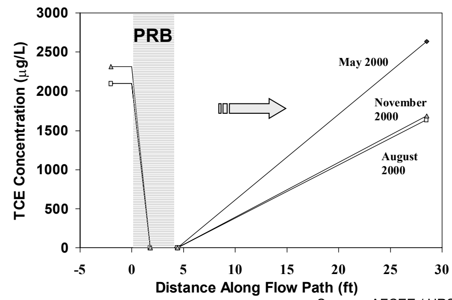
Warren AFB, WY



Source: AFCEE / URS Corporation, 2001

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Unsupported Excavation

- Trench excavated without support
- Formation does not collapse
- Iron or iron sand mix placed directly into excavation
- Inexpensive construction
- Limited to shallow depths

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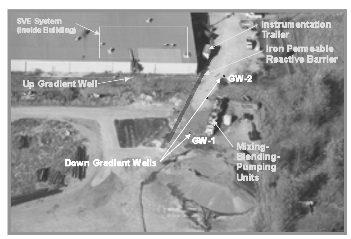
Vertical Hydraulic Fracturing, Iowa



Continuous PRB

- Installed Nov 1999
- 240 ft total length
- 3-inches thick
- Installed 25 ft to maximum 75 ft bgs

Influent Groundwater:

- 3 mg/L TCE

GOLDER SIERRA

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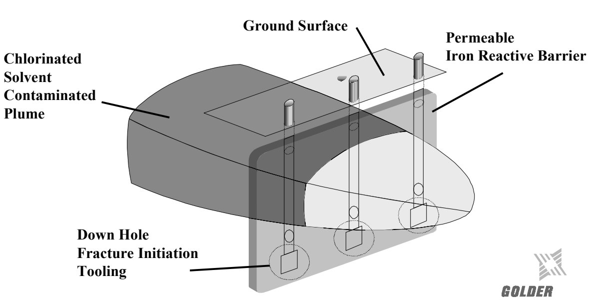
Vertical Hydraulic Fracturing



GOLDER SIERRA

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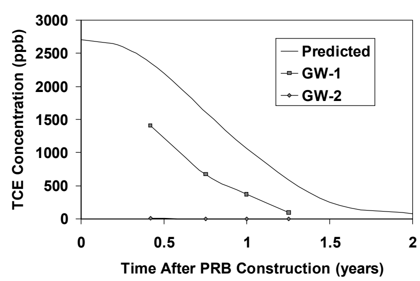
Vertical Hydraulic Fracturing, Iowa



GOLDER SIERRA

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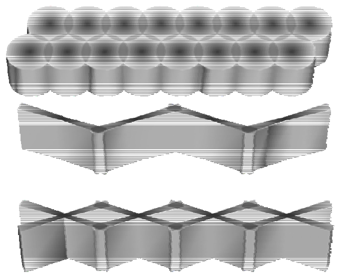
Jetting Geometries

Columnar:

Diaphragm:

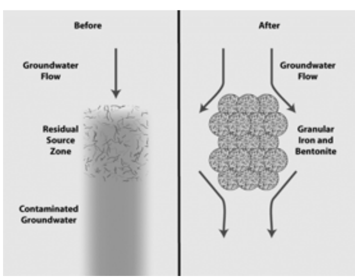
Dual Diaphragm:



Installation In Fractured Bedrock

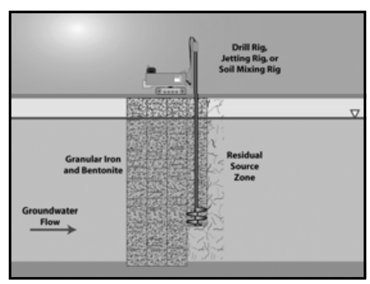
- Refractive flow and treatment
  - discrete blasting creating high K zones
  - in-situ treatment zone
- Pneumatic fracturing and injection
- Blasting and excavation
- Array of boreholes
- Permeation grouting (fracture infilling)
- Pump-and-treat with above-ground system

Treating DNAPL Source Zone



- Reduced permeability results in:
  - long residence time for DNAPL dissolution and degradation by iron
  - low VOC mass flux out of source zone

Treating DNAPL Source Zone



- Iron and clay (bentonite/kalonite) mixed into source zone

Long-term PRB Performance

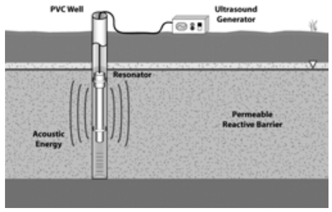
- consistent performance with respect to VOC degradation rates
- greater than 7 year track record
- no evidence of microbial fouling under flowing conditions
- precipitate formation will influence long-term performance

Hydraulic Performance Issues

- Hydraulic by-pass of contaminants due to:
  - incomplete plume capture
  - change in seasonal flow direction
  - underflow or overflow
  - Permeability reduction due to construction
- Reduced residence time due to flow velocity variation along line of installation

PRB Operations and Maintenance

- Ultrasound
- Hydraulic pressure pulsing
- Replacement



Lump sum should be budgeted into O&M every 10 years

Sources of Information

- www.rtdf.org
- www.eti.ca
- cgr.ese.ogi.edu/iron
- www.itrcweb.org
- www.prb-net.org
- www.epa.gov/tio

For further information please contact us:

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Waterloo, Ontario, Canada N2V 2G6

Tel: 519-746-2204
Fax: 519-746-2209

email: eti@eti.ca
web: www.eti.ca

Zero Valence Iron Injection for Source Treatment

- *"An Advanced Solution for In-situ Chemical Reduction "*
  - ***Presented by John Liskowitz***
  - ***President - ARS Technologies Inc.***

Effective In Situ Chemical Reduction Using ZVI Injection Is Dictated by Four Elements

Selection of Material which provides treatment performance, cost effectiveness and no hazardous effect.

Contact between the injected ZVI and the target compound

Quantity of ZVI Powder injected in the subsurface

Uniformity of injected ZVI to mirror target contaminant distribution

Mechanism(s) of ZVI Injection

Mechanism 1: Fluidization of Geologic Matrix

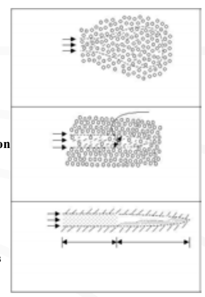
-Typical in Sand/Gravel Media

Mechanism 2: Fluidization w/some discrete channelization

-Typical in Sands/Silts/Minor Clay

Mechanism 3: Discrete Channelization/Fracture Emplacements

-Typical in Clays/Fracture Rock Media



Gas Atomized Injection Used to Emplace Iron

Hydraulic Pumping

Liquid Atomization

Overview - Ferox[SM] Process

<u>Ferox [SM] Process</u>

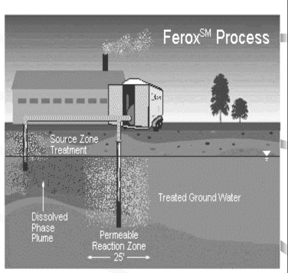
U.S. Patent # 5975798 November 1999:

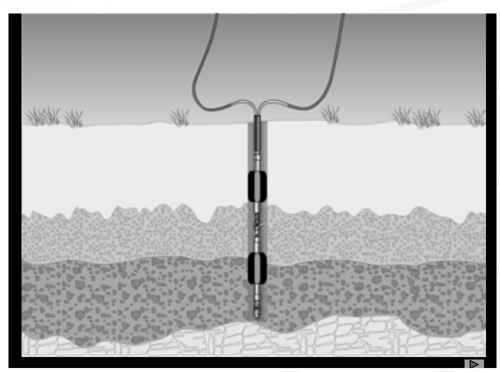
*Capable of treating dissolved phase **<u>and</u>** source contamination*

Injections possible underneath existing structures/utilities

Not limited by depth of application

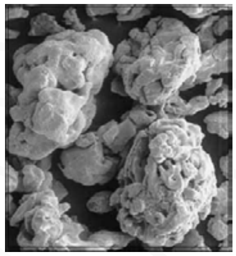
Iron powder dosage emplaced to mimic in-situ contaminant concentration





Ferox℠ Material is a Highly Reactive Pure Iron Powder

- Irregular Shape Provides Maximum Surface Area
- **FDA Certified 95+% Pure**
- Trace Carbon - Provides Enhanced Reaction Benefits
- 40-80 um size particles
- Cost $1.45 - 1.70/lb



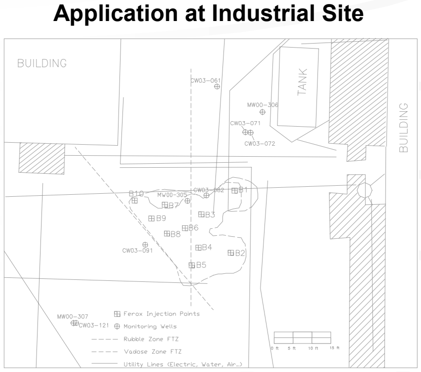
Current Technology Status

- 22 laboratory treatability tests completed
- 12 field systems completed
  - **Largest 45,000 square feet**
  - **Deepest 110 feet**
- 6 systems currently being installed

Application Equipment -

Application - Ferox℠ Pre Injection Conditions at Site

Application at Industrial Site



Application - Ferox℠ Injections

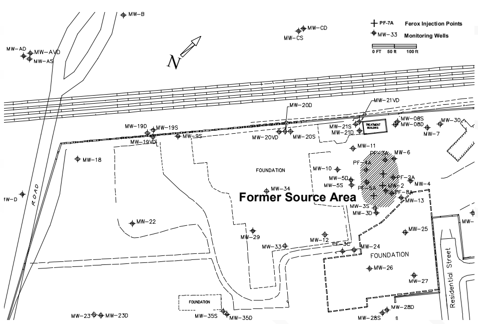
Case Study #1 Fractured Bedrock Aquifer

NJ ISRA Site, Central New Jersey

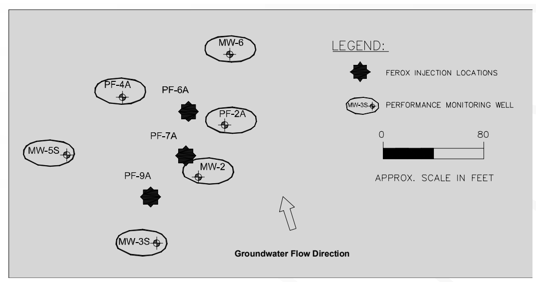
Site Background

- Historic discharge of TCE into a weathered shale/siltstone formation
- Dual-Phase Extraction (DPE) enhanced by Pneumatic Fracturing installed and operated 1995-2001
- In six years = ~400 lbs of VOC from site
- TCE reduced from 170,000 ug/L to less than 3,000 ug/L in Source Area
- but….Mass Removal Rate of DPE went asymptotic

Site Map

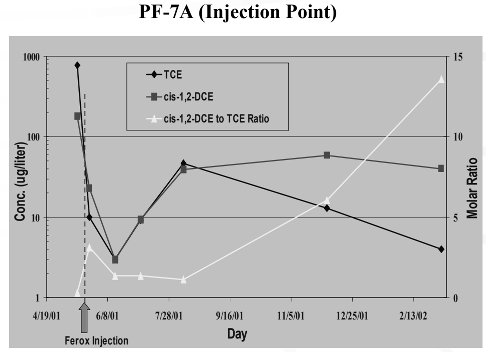


Pilot Test Injection Area



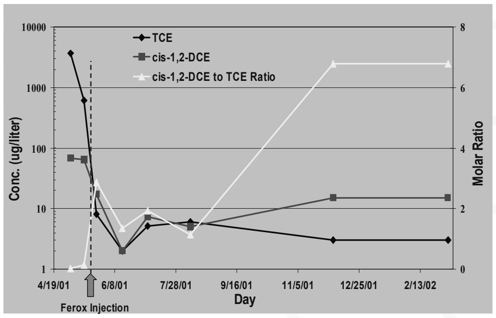
Concentrations vs. Time

PF-7A (Injection Point)



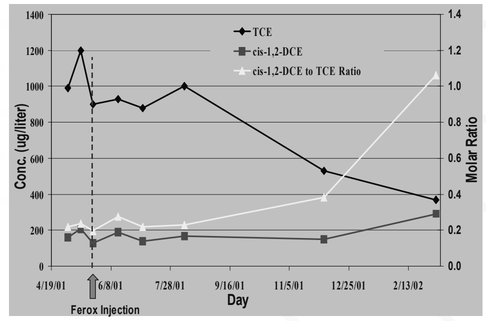
Concentrations vs. Time

MW-2 (Injection Area)



TCE Concentration vs. Time

MW-5S (Side-gradient)



pH Effects

Ferox Injections

Well ID	pH (SU)							
	5/3/01	5/14/01	5/24/01	6/14/01	7/5/01	8/9/01	12/4/01	3/8/02
MW-2	7.42	7.46	9.56	8.60	9.17	10.03	9.22	9.24
MW-3S	7.83	7.68	8.05	7.69	7.67	7.77	7.85	7.93
MW-5S	7.57	7.50	7.77	7.90	7.68	7.87	7.60	8.04
MW-6	8.15	8.06	8.18	8.22	8.07	8.10	8.02	7.93
PF-2A	7.22	6.87	7.55	7.68	7.54	7.38	7.52	6.59
PF-4A	7.57	7.25	9.25	9.08	8.73	9.16	7.45	8.24
PF-7A	NS	6.62	9.22	8.20	6.95	8.91	9.12	8.25

Dissolved Oxygen Effects

Ferox Injections

Well ID	DO (mg/l)							
	5/3/01	5/14/01	5/24/01	6/14/01	7/5/01	8/9/01	12/4/01	3/8/02
MW-2	6.42	5.35	0.00	0.00	0.00	1.76	0.00	0.00
MW-3S	0.56	1.36	0.28	0.00	0.00	2.23	0.00	0.00
MW-5S	0.00	0.96	0.00	0.00	0.00	0.00	0.00	0.00
MW-6	10.49	8.56	1.20	0.00	0.00	0.00	0.71	0.00
PF-2A	7.08	5.29	1.61	0.00	0.00	0.00	0.00	0.77
PF-4A	1.08	0.22	0.00	0.00	0.00	0.00	0.00	0.00
PF-7A	NS	4.56	0.00	0.00	0.00	2.23	0.00	0.00

Redox Potential Effects

Ferox Injections

Well ID	ORP (mv)							
	5/3/01	5/14/01	5/24/01	6/14/01	7/5/01	8/9/01	12/4/01	3/8/02
MW-2	125	128	-542	-496	-403	-715	-314	-212
MW-3S	268	109	165	5	65	-62	80	95
MW-5S	248	108	-257	-26	49	-66	-78	-66
MW-6	280	116	-126	114	103	6	71	0
PF-2A	156	192	-162	-362	-215	-211	-144	95
PF-4A	120	136	-659	-533	-535	-335	-190	-251
PF-7A	NS	178	-580	-537	-449	-483	-359	-281

Project Summary and Future Status

- Ferox[SM] treating residual TCE not addressed by SVE/P&T system
- RAW Submitted proposing expansion of pilot-test zone injections in 2003
- Application cost \$5 -\$8 per pound of iron Emplaced

Summary of Results

- TCE Reduced by up to 99%
- No rebound observed in most wells 10 months after injections
- Geochemical parameters responded to ZVI as expected:
  - **DO decreased to zero in nearly all wells**
  - **pH increased by 0.2 to 1.8 s.u.**
  - **ORP decreased significantly in all wells by 79 to 459 mv**
- Injection pressure less than 120 psi.
- Injection pressure influence generally uniform in all directions

Case Study #2- NASA's MSFC
Source Area 2
Huntsville, Alabama

Source Area 2 Site Background and History

•Located adjacent to former Rocket Test Stand

•Holding Pond Used for Coolant Water Believed Source of TCE

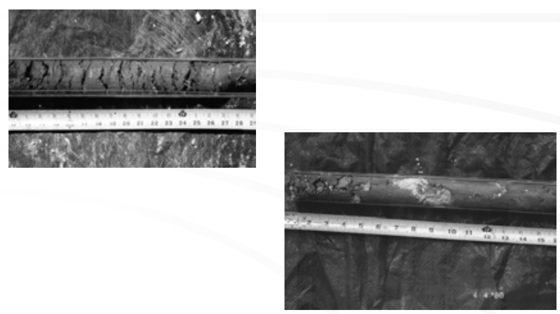
• Impacted Area along sewer line originating from Holding Pond

• TCE source area and groundwater plume

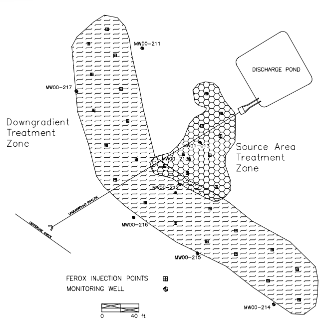
• Presence of UXO prevented digging at surface

• Industrial sewer, high pressure gas line present in area

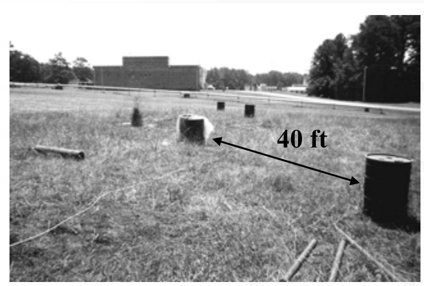
Source Area 2 - Soil Cores



Source Area 2 - Case Study

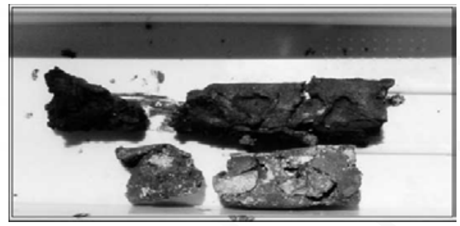


Source Area 2 - Field View



Injection Event

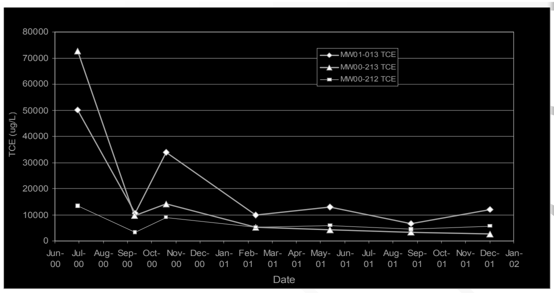
Soil Sampling - Ferox^{SM} Injection Zone and Background Cores



Ferox^{SM} Post-Injection GW Sampling SA-2

TCE Concentrations

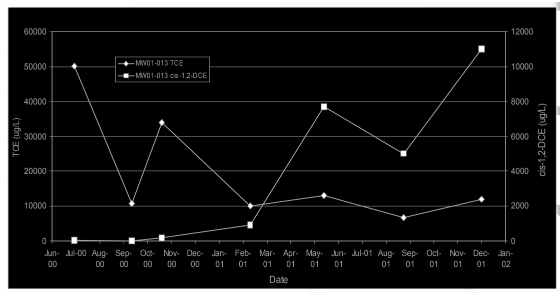
(Source Area Wells)



Ferox^{SM} Post Injection GW Sampling SA-2

TCE and cis-1,2-DCE vs. Time

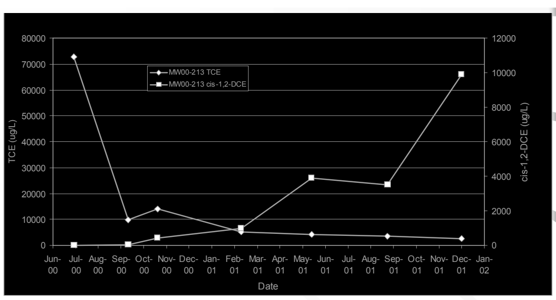
(MW01-013)



Ferox^{SM} Post Injection GW Sampling SA-2

TCE and cis-1,2-DCE

(MW00-213)



Chloride Mass Balance Within 97 %

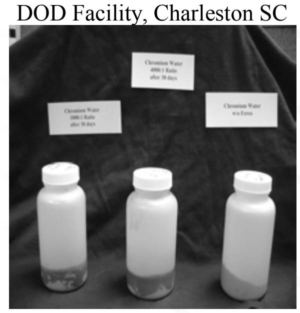
Station ID	Observed TCE Reduction (mg/l)	Chloride Production (mg/l)	Observed DCE Production (mg/l)
MW01-013	26.2	16.2	4.9
MW00-211	0.0	2.9	0.0
MW00-212	6.1	5.6	0.5
MW00-213	65.2	36.7	8.0
MW00-214	0.0	0.1	0.0
MW00-215	0.0	0.7	0.0
MW00-216	-0.1	2.3	-0.1
MW00-217	0.0	2.6	0.0
Total (mg/l)	97.4	67.1	13.3
Total (mmol/l)	0.74	1.89	0.14

Total TCE Reduced Due to Chloride and DCE Production- 0.72 mmol/l
Mass balance closes within about 97 %

Project Summary

- 20,000 lbs of Ferox Material Injected
- Target Depths to 37 feet
- Gas and Slurry Injected 60+ feet Using
- Pressures ranging from 60 to 120 psi
- Projected Cost For Field Application
  $17/Pound Iron Injected

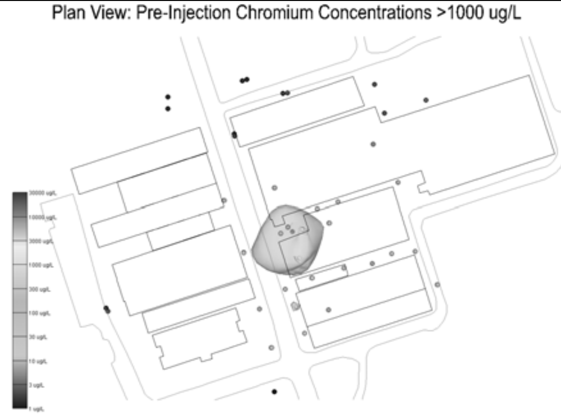
Cr+6 Source Reduction
DOD Facility, Charleston SC



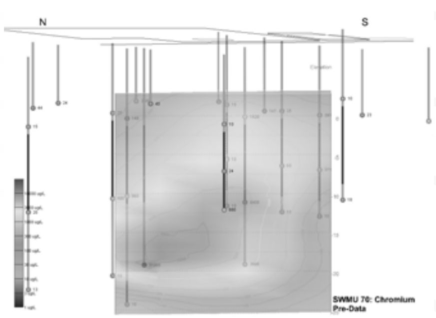
Site Background

- Plating Shop, source of Cr+6 in groundwater
- Electrical Vault and Corridor under building flooded with high levels of Cr+6 solution
- Previous Treatment Include removal of old plating shop, contaminated soil, contaminated water in vault, and vault
- Geology Consists of fine sands and sandy silts interbedded with sand to confining unit
- Thin plastic clay stringers also present

Plan View: Pre-Injection Chromium Concentrations >1000 ug/L



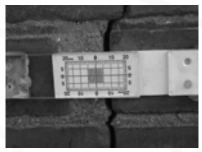
Cr^{6+} Pre-Treatment Profile View - Cross Section



How Safe Injections Were Applied Under Building

- Thorough review of structural drawings and utility maps
- Computer Modeling to Assess Movement Cause and Effect Loads
- Documentation of Pre-existing Condition
- Develop Site Empirical Data Prior to injecting within Building.

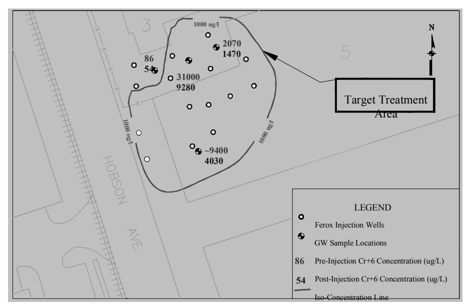
Injection Approach Under Building Required Modeling and Documentation of Existing Condition



Project Summary

- Injections completed January 2002
- Minimal disruption to tenant activities in building (no lost time for tenant)
- 37,000 lb ZVI injected
- Post-treatment GW sampling monitoring Cr+6 and GeoChemical Parameters

Post Injection Results After 6 Months



GW Geo-chemical Parameters (Initial 5 Months)

Ferox Injection (each well)

Parameter	70GW001 (shallow)			70GW01 (deep)			70GW006(deep)			70GW06(deep)		
	4/5/01	5/9/01	7/11/01	4/5/01	5/9/01	7/11/01	4/5/01	5/9/01	7/11/01	4/5/01	5/9/01	7/11/01
pH (SU)	6.12	5.8	5.77	6.07	6.4	8.84	NS	NS	6.03	NS	NS	9.17
Temperature (deg. C)	17.9	21.8	25.18	20.9	22.6	22.8	NS	NS	22.7	NS	NS	22.5
Turbidity (NTU)	64	16	0	110	46	250	NS	NS	23.5	NS	NS	125
DO (mg/L)	**5.4**	**0.84**	**0.67**	**0.4**	**0**	**0**	**NS**	**NS**	**0**	**NS**	**NS**	**0**
ORP (mV)	**192**	**176**	**172**	**216**	**144**	**-129**	**NS**	**NS**	**32**	**NS**	**NS**	**-222**
Eh (mV)	392	376	372	416	344	71	NS	NS	232	NS	NS	-22
Conductivity (uohms)	15	0.19	0.177	57	0.8	0.812	NS	NS	0.232	NS	NS	0.323
Total Cr (ppb)	2580	1680	2000	30600	14100	12500	NS	NS	6850	NS	NS	504
Cr 6+ (ppb)	**2070/2500***	**1450**	**1420**	**31000**	**14800**	**9200**	**NS/9400***	**NS**	**4030**	**NS/3680***	**NS**	**16**

baseline
post-injection
NS - Well not sampled
* - Hydropunch

Progress/Results to Date

- Center MW shows 70% reduction in Cr+6 concentrations
- Water quality parameters change more prevalent in Deep Wells compared to Shallow Wells
  - D.O. decreased to zero in three of four MW's
  - Hydrogen increased at deep well (14 to 29,000 nM)
  - ORP reduction to negative in deep wells (-)
  - pH increased from 6.07 to 8.84 (5 months)
  - Potential round of polish injections for Shallow Zone Planned

Interesting Observations

⇒ GW Geo-Chem. Data shows Delayed Effect Microfilm Coating on Iron Particles?
(Reference Farrell et. al ES&T 2001)

⇒ Measurement of Hydrogen (Microseeps) good parameter to monitor (14 to 29,000 nM increase in Center of Source Area)

⇒ Total Cr measurement in ground water decreasing. (Migration or Sampling Method Issues???)

Ferox sm Applications in New Jersey

Site Desc.	Type	Scope	Status	Cost Factor	Results
1999 ISRA Site Passaic County, NJ	Pilot Test CVOC's	150 ft by 20 ft 4,400 lbs Fe	2.0+ years	$35 /lb Injected	Iron May be 90% TCE Reduction Prior to Rebound
2000 DOD Site Northwest NJ	Pilot Test Cell VC, Cis- DCE	30 by 60 feet 10,000 lbs Fe	2.0 years	$15/lb Injected	Downgradient VC reduced 85%, Cis-DCE 94% Inside Reaction Zone 100%
2001 ISRA Site Fractured Bedrock Central N.J.	Pilot Test CVOC's	100 by 40 ft. 4,000 lbs Fe	1.0 Year	$6 / lb Injected	95% + Reduction within Treatment Zone GW Geochem Changed
2002 Burnt Fly Bog, Marboro NJ	Lab BenchScale PCB's and Pb	N/A	Draft Report Sub. to EPA	N/A	Complete Pb reduction, PCB Partial Reduction

THE END

- www.arstechnologies.com
- www.ifracture.net